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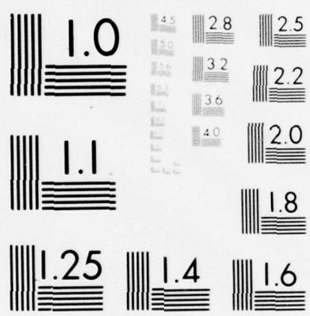
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# PRECISION FORGING OF SPIRAL BEVEL GEARS.


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This program consisted of the production of precision hot forged spiral bevel helicoptor gear sets using methods previously developed under AVSCOM sponsorship. Forging was performed at TRW on a mechanical press using two forging blows, performed in rapid succession with reheating, to obtain forgings with integrally forged tooth forms. The geometry of the as-forged tooth forms were controlled such that the resultant machining stock envelope was suitable for carburising and finish grinding. The parts were finished and then shipped

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to Boeing-Vertol Co. for qualification testing. The objective of this program is to qualify a process which will produce gear blanks which are metallurgically superior and cheaper to finish than blanks made by conventional methods.

## FOREWORD

This Manufacturing Methods and Technology Report describes the work performed under Contract DAAJ0173-C-0913 (PIG) during the period June 29, 1973 thru December 31, 1976. This report is being submitted in accordance with Contract Item 0002, Exhibit A, Sequence No. A003.

The program work was performed by the Materials Technology Laboratory, TRW Equipment, TRW Inc., 23555 Euclid Avenue, Cleveland, Ohio 44117. The Program Manager was Paul M. Gillespie and the Program Engineer was Roger R. Skrocki. The interest and assistance provided by Mr. A. Lemanski and Mr. R. J. Drago of Boeing Vertol and by Mr. A. Coppe of Litton Precision Gear is gratefully acknowledged.

This project was accomplished as part of the U.S. Army Aviation Systems Command Manufacturing Technology program. The primary objective of this program is to develop, on a timely basis, manufacturing processes, techniques, and equipment for use in production of Army material. Comments are solicited on the potential utilization of the information contained herein as applied to present and/or future production programs. Such comments should be sent to: U.S. Army Aviation Systems Command, ATTN: DRSAV-EXT, P.O. Box 209, St. Louis, Missouri 63166.

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# 1.0 INTRODUCTION

This Final Manufacturing Methods and Technology Report presents the results of a program performed by TRW Inc., Cleveland, Ohio to furnish twenty-six (26) sets of spiral bevel helicoptor gears made from AMS 6265 steel forgings in which the tooth forms have been precision hot forged to a semi-finished configuration. The gear sets were forged at TRW in accordance with a process developed under Army sponsorship, finished under subcontract at Litton Precision Gear Co. and finally shipped to Boeing-Vertol, Philadelphia, Pennsylvania for dynamic testing under direction of the Army Aviation Systems Command. The ultimate goal of this forging and testing program is to qualify this specific precision gear forging process for production use.

In accordance with contract provisions this report presents details of the forging process used to produce the gears including material certifications, applicable inspection results and observations relevant to the future implementation of the process. Also included for information is a brief summary of the background and current status of the gear forging process at TRW for the subject gear set.

## 2.0 BACKGROUND

Under AVSCOM sponsorship, TRW had developed a precision hot forging process for producing CH-47 helicoptor transmission gear blanks containing integrally forged tooth forms. This process was developed because of the potential it offers for producing a metallurgically superior gear set with resultant improvements in mechanical properties for critical helicoptor applications. Also, the process offers the potential for reduced gear delivery time and cost.

The gear set chosen for this development and testing program was the CH-47 helicoptor main transmision spiral bevel gear and pinion. These gears, produced from AMS 6265 steel, transmit engine power at high speed to the reducing gear train to drive the main rotor. Basic gear and pinion drawing dimensions are given in Table 2.1.

The current and conventional method for manufacturing these types of gear sets consists of hot upset forging of round bar stock to form a pancake shaped gear blank from which the gears are machined. Gleason gear grinding machines are used to machine the tooth forms using a series of rough cuts to generate the semi-finished tooth forms and then a series of finish grinds to meet final size and surface finish. Carburizing and heat treating are performed between rough and finish grinds, and the amount of stock removal left for finish grinding is carefully controlled to take best advantage of the surface properties produced by carburizing.

The TRW precision forging process used in this program produces gear and pinion blanks with integrally forged teeth which are controlled in size so that the teeth can be carburized and finish ground without rough cutting. The appearance of the as-forged and finished gear set is illustrated in Figure 2.1. The technique for precision forging the gear blanks involves the use of a mechanical crank type forging press. The press is a conventional design single action type, widely available in industry and capable of high speed production.

For the CH-47 helicoptor gear set chosen for this program, forging is performed in 2 blows consisting of a hot preform blow followed immediately, without reheating, by a hot coining blow which forms the tooth details. The configuration of the starting billet, preform forging and final forging, as they appear in the above described forging sequence is shown in Figure 2.2 for the pinion gear. The deformation sequence for the mating gear is shown in Figure 2.3.

During process development, which is described in detail in the Final Report for Contract DAAJ01-69-C-0614, the major development tasks were: (1) determination of the optimum forging die cavity size to produce tooth forms with a uniform and controlled envelope of grinding stock, (2) development of forging ejection methods to prevent deformation of the tooth form during ejection of the hot forging from the tooth form die, (3) development of billet plating and plating stripping for protection against oxidation during forging, and (4) development of billet and preform design to achieve sound and consistent filling of the tooth

Table 2.1

Basic Gear and Pinion Dimensions

| | Pinion | Gear |
|---|---|---|
| Number of Teeth | 35 | 43 |
| Pitch | 4.930 | 4,930 |
| Pressure Angle | 22°30' | 22°30' |
| Spiral Angle (Mean) | 25°0'' L.H. | 25°0'' R.H. |
| Pitch Diameter | 7.099 | 8.722 |
| Pitch Angel (Basic) | 39°9'' | 50°5' |
| Root Angle (Basic) | 37°1' | 48°11' |
| Face Angle | 41°49' | 52°59' |
| Circular Tooth Thickness | 0.344 to 0.337 | 0.291 to 0.294 |
| Addendum | 0.199 | 0.146 |
| Dedendum | 0.184 | 0.237 |
| Normal Chordal Thickness at P.D. | 0.287 | 0.241 |
| Load Side of Tooth | Concave | Convex |

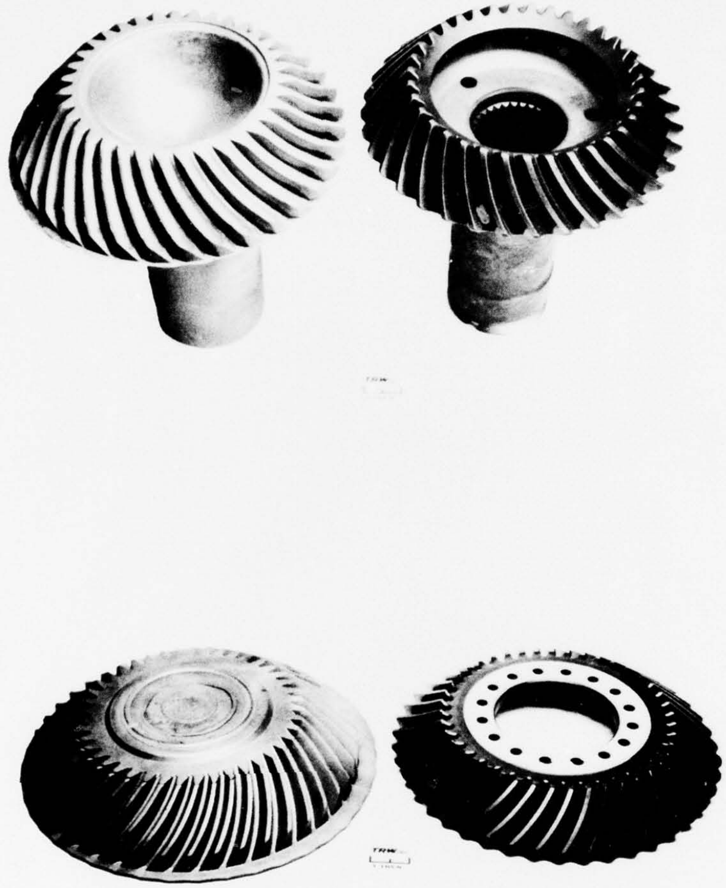

Figure 2.1. Spiral Bevel Gear Set. Top: As-Forged Gear, Left; Finished Gear. Bottom: As-Forged Pinion, Left: Finished Pinion.

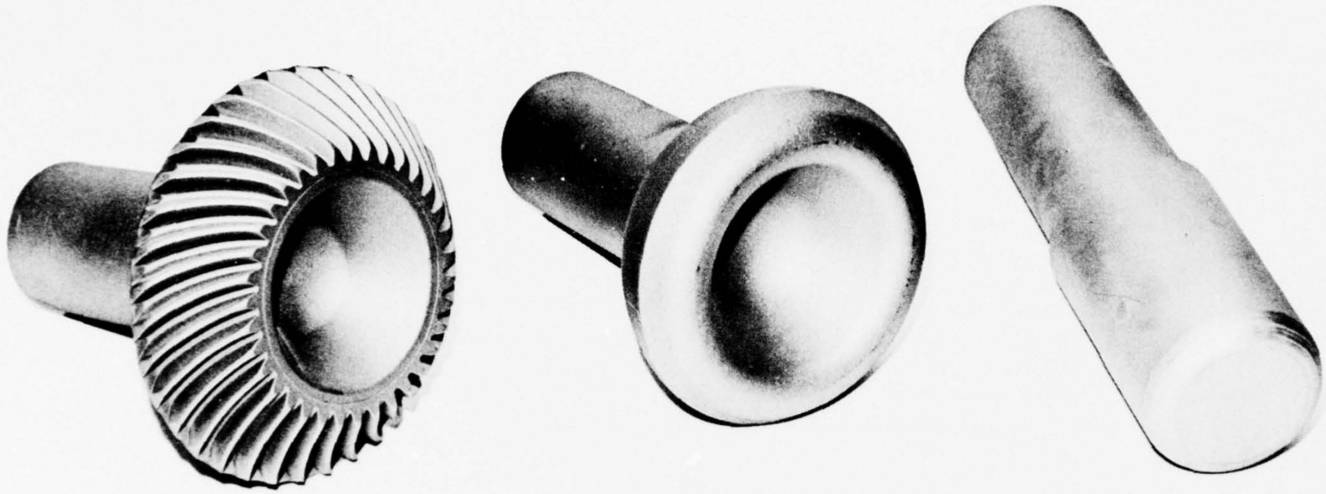


Figure 2.2. Sequence of Deformation for Pinion Forging.



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Figure 2.3. Deformation Sequence for Gear Forging.

form die. These process development efforts have led to a number of special tooling and forging methods which constitute the only known successful process for hot forging the difficult spiral bevel gear configuration. A summary of some of the basic forging data for this process is listed in Table 2.2.

The finishing of gear sets, which is performed by Litton Precision Gear Co., consists of essentially the same basic finishing operations as is used for finishing gears that are cut from conventionally forged gear blanks. The tooth forms themselves approximate the envelope of grinding stock exhibited by a typical Gleason rough ground blank. Some minor modifications are required to accomodate the forged shape away from the tooth forms. The range of stock removal on the tooth forms experienced during the finishing of forged gears during process development versus conventional cut gears is presented in Table 2.3.

Results of a metallurgical evaluation of forged gears performed during process development indicated that forged gears exhibit an improved metallurgical structure compared to cut gears. In particular, mechanical fibering was shown to be essentially parallel to the tooth surface, and this is expected to provide improved tooth toughness compared with conventionally cut gear teeth which typically exhibit "end grain" pattern and fibering perpendicular to the tooth surface. An example of the favorable forged tooth microstructure is shown in the tooth cross-section in Figure 2.4.

Results of single tooth fatigue testing performed on the spiral bevel gears during the manufacturing development program (Contract DAAJ01-69-C-0614) indicate that the forged tooth is at least equivalent to the cut tooth in fatigue properties. Because of the difficulty in comparative testing of spiral bevel gears in overload conditions no comparative data was obtained during process development on this particular gear set. However, in tests performed by other investigators on forged spur gears, which can be more easily tested, forging of the teeth was shown to produce significant improvements in tooth strength properties.

The forging of spiral bevel gears and pinions was viewed to be a way of reducing the expensive and time consuming rough cut operations on the limited number of available Gleason machines. This could be a vital consideration under mobilization conditions.

This program to supply twenty-six sets of spiral bevel gears made from forgings with integrally forged teeth represents a major step toward qualification of the forging process for production. The gears furnished will be allocated by AVSCOM to Boeing-Vertol for dynamic testing in accordance with accepted qualification procedures. TRW is interested in achieving full qualification of this process.

Table 2.2

Gear Forging Data

Material - AMS 6265 CVM steel, hot roll finished bar

Billet Size - 3-1/2 in. diameter x 4-1/2 in. long (gear)
3-1/2 in. diameter x 11-7/8 in. long (pinion)

Heating Temperature - 1950°F-2050°F - 45 minutes

Billet Heating Atmosphere - exogas, 7:1 ratio

Die Temperature - 400°F

Transfer Time Furnace to Preform Die - 10 s, average

Transfer Time Preform Die to Coin Die - 12 s, average

Coining Load - $3.5 \times 10^6$ pounds

Table 2.3

Range of Stock Removal

| | Coast Side | Drive Side | Root |
|---|---|---|---|
| Cut Pinion (semifinished) | 0.007 to 0.010 in. | 0.006 to 0.010 in. | 0.005 to 0.009 in. |
| Forged Pinion (as-forged) | 0.008 to 0.013 in. | 0.005 to 0.008 in. | 0.005 to 0.014 in. |
| Cut Gear (Semifinished) | 0.009 to 0.011 in. | | |
| Forged Gear (as-forged) | 0.008 to 0.011 in. | | |

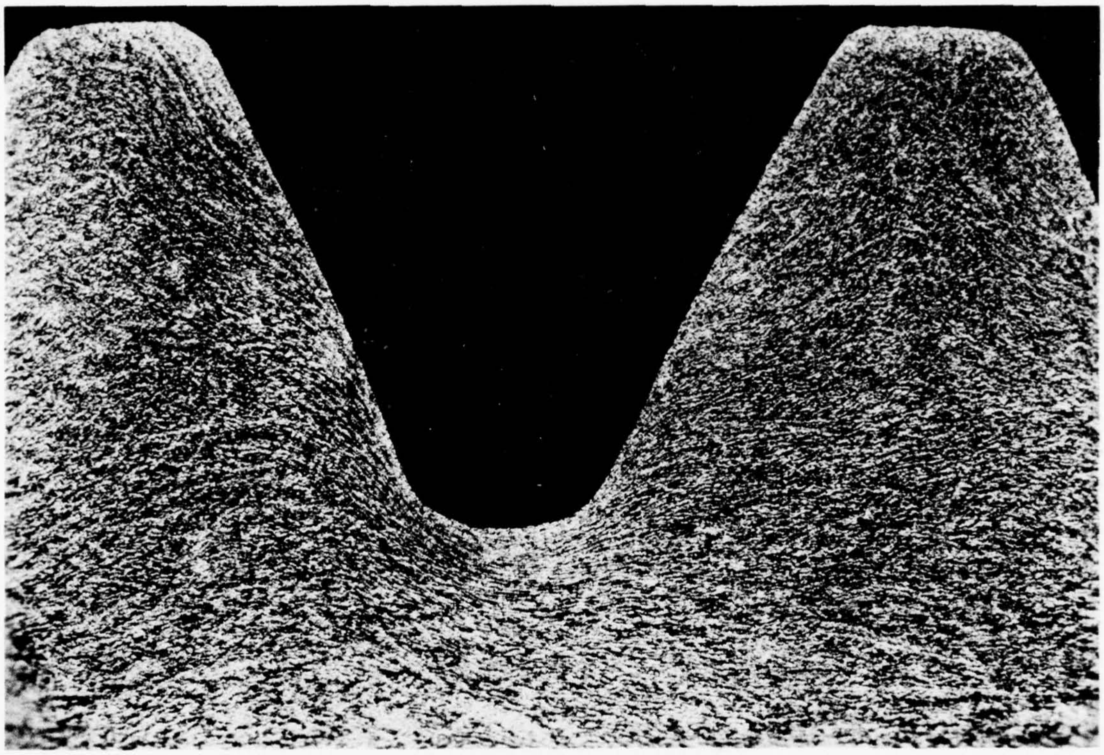


Figure 2.4. Cross-Section of Forged Tooth, Etched to Show Forging Flow Lines.

## 3.0 PROGRAM SCHEDULE

The program approach used to produce the deliverable finished gear sets consisted of three phases as described in TRW's Proposal CR#M-821. A description of these phases is presented below.

### 3.1 Phase I, Proofing of Tooling and Equipment

The first program phase consisted of tool proofing to verify the operative status of the forging tooling. At the start of the program TRW had a set of forging tooling which had been subjected to wear tests during a simulated production run during the process development program. It was necessary to inspect and refurbish the forging tooling by replacing and/or EDM resinking the tooth form die. After refurbishment it was necessary to verify that the tooling was capable of producing tooth form forgings which possessed the required finishing stock on the tooth surfaces.

The metrology available for evaluating the critical dimensional characteristics of the spiral bevel teeth was not sufficient to measure the forging in a way that would assure proper distribution of grinding stock for finishing the teeth. Tool proofing was to be accomplished empirically by producing a small quantity of forgings made from an air melt version of the gear steel and then submitting these forgings to Litton Precision Gear Co. for tooth form grinding trials. The utility of the forging dies was judged on the results of these tooth grinding operations.

In addition to tool proofing, these trials served to prepare the forging equipment and to reactivate the skills of the gear finishing subcontractor for handling the integrally forged gear teeth.

### 3.2 Phase II, Production Forging

The approach toward producing the twenty-six sets of gear forgings which were finished and delivered for testing consisted of using the same forging process as that developed and documented by TRW under AVSCOM Contract DAAJ01-69-C-0614. This includes the drawing requirements and the process parameters for producing precision forged gear blanks to TRW engineering Drawings SK091460 (gear) and SK091570 (pinion). In accordance with the Description of Work (Section F.2) set forth in the contract, the material from which the gears were forged conformed to AMS 6265 requirements. The raw material bar stock was 3.50 inches in diameter and was finished machined to remove all surface defects. The billet material used during the forging process was to be treated with nickel plate to eliminate the formation of scale and pitting on resulting forged tooth surfaces. After the gears were forged, a controlled nickel stripping procedure was to be used to insure complete removal without excessive etching, leaving a smooth surface suitable for carburizing and finish grinding.

It was intended that the forging of these gear sets be accomplished in the same manner as that which would be used during full scale production. Because the delivered gear sets will be tested for qualification of a process, the process used to forge the gears remained basically unchanged through this qualification activity.

## 3.3 Phase III, Gear Finishing

As set forth in the contract, finishing of the forged gear blanks was to be performed to meet Boeing engineering Drawings SK22270 (114D6245) and SK22269 (114D6244). The process used for finishing had been especially developed for forged tooth blanks. The forged teeth are used to locate the blank in a special three point locating fixture to machine the mounting surfaces. After these critical mounting surfaces are established, the remaining finishing operations on the teeth are the same as for producing the parts by the conventional method.

Gear finishing was performed by Litton Precision Gear Co. who is the current supplier of the subject gear set and who performed finishing for TRW during process development on Contract DAAJ01-69-C-0614.

# 4.0 RESULTS AND DISCUSSION

## 4.1 Tool Proofing Phase

A tool proofing phase was undertaken to verify the adequacy of the equipment and tooling on hand from the development program to produce the optimum forging configuration.

### 4.1.1 Equipment Preparation

#### 4.1.1.1 Forging Press

A new motor pulley was installed on the 2000-ton mechanical forge press to increase the flywheel speed from 40 to 80 rpm and thereby produce the required energy for gear and pinion forging. The installation of new drive belts and other accessories required for gear forging such as tool heating torches and ejector rods was performed.

The standard production tooling nests were removed and replaced by a heavy die nest built for the gear forging during the previous gear forging development contract. This die nest consists of precision die holders and two guide columns to maintain alignment of punch and die during the forging stroke.

#### 4.1.1.2 Heating Equipment

For heating the forging billets to the hot forging temperature range, a General Electric rotary hearth furnace was moved to the vicinity of the forging press. A pipe line with a gas flow meter was installed to supply exogas to the furnace chamber. A natural gas flame curtain was installed at the entrance of the furnace to burn off excess exogas and to minimize oxygen contamination of the furnace atmosphere.

To assure that the exogas system was adequate to prevent scaling of the plated forging billet at 2050°F, a trial heating run was made with a nickel-plated steel bar sample. With this sample it was found that an exogas flow of 700 $ft^3$/hour was sufficient to prevent any appreciable scaling of the billet during heating.

### 4.1.2 Refurbishment of Forging Tooling

#### 4.1.2.1 NDT Inspection

Gear and pinion forging tooling, available from the development contract, was dimensionally inspected and dye penetrant inspected. Particular attention was given to the punches and dies which contact the work during forging. The gear preform dies, which had been used for a production run to study die wear and forging reproducibility, were found to be heat-checked and required resinking. The hot coining tooling, which includes the tooth form punch, was found to be in good condition. Because this tooling had produced good forgings during the final phase of the development program it was decided not to resink them.

#### 4.1.2.2 Reworking of Gear Tools

The gear preform tooling was resunk to eliminate severe heat cracking on the working surfaces. Resink depths of 0.160" and 0.156" were required on the die and punch respectively to completely clean up all deteriorated surfaces. During the machining of these tools, dye penetrant was used to monitor the progress of crack removal. Increments of .030-.040" metal removal depth were cut until no indications were seen by dye penetrant inspection.

The action of the cutting tool on the preform dies and punch during resinking indicated that the heat of forging produced a soft surface layer over .100" deep on the working surfaces. This layer was removed by the resink depths indicated above. To compensate for the depth of resink, two shim plates were machined to a thickness of 0.156" and 0.160" in order that the correct shut height could could be obtained in the forging press. Material from the development contract was on hand for these shims.

#### 4.1.2.3 Reworking of Pinion Tools

Because of the severe crack in the hot coin pinion punch which contained the tooth form, a new punch was made. Material for the replacement punch was available from the development program in the form of a semifinished heat treated H-26 steel slug which was complete except for the tooth form cavity. The tooth form was machined by the EDM method using electrodes available from the third and final development pinion configuration. EDM machining data for the pinion is shown in Table 4.1. Three basic types of electrodes were used as indicated in the table. These consisted of the "8M" series graphite electrodes designed with large overburn for rapid rough cut, the "8S" series graphite with .015" overburn for semifinish, and "BS" series brass with .001" overburn for finish cut. A cam was used on the EDM holding fixture to provide an average rotational lead angle of 17°50'. This lead angle was found to minimize cutting time.

The EDM resinking of the pinion uncovered a 1/8" diameter hole in one of the tooth cavities near the bottom of the punch cavity. It was found that this hole was the extension of a thermocouple hole extending through the entire punch thickness. Apparently the hole had been drilled too deep during the semifinish machining operation. Re-examination of the tool drawing showed that the actual depth of the hole was approximately 5/16" longer than called for. A decision was made to use the punch with the hole because the location of the hole

Table 4.1

EDM Parameters for Pinion Tooth Form Punch

| Electrode Serial No. | Height "A" Dimension (per Drawing) Start | Finish | Cutting Time (hours) | Volts | Amps | Frequency (cps) | Dielectric Oil Pressure (psi) | Metal Removal |
|---|---|---|---|---|---|---|---|---|
| P3-8M-3 | 1.625 | 2.025 | 12.5 | 60/65 | 20/24 | 16,000 | 20 | 0.400" |
| P1-8M-3 | - | - | 3.5 | 60/65 | 20/24 | 16,000 | 20 | 0.005" |
| P2-8M-3 | - | 2.030 | 1.7 | 60/65 | 20/24 | 16,000 | 20 | |
| P1-8S-3 | 2.030 | - | 1.5 | 70 | 15 | 32,000 | 20 | 0.005" |
| P2-8S-3 | - | 2.035 | 1.4 | 70 | 10 | 65,000 | 20 | |
| P3-8S-3 | 2.035 | 2.037 | 3.5 | 70 | 10 | 65,000 | 20 | 0.002" |
| P4-BS-3 | 2.037 | 2.044 | 8.0 | 100 | 5 | 130,000 | 20 | 0.007" |
| P3-BS-3 | 2.044 | 2.047 | 3.0 | 100 | 5 | 130,000 | 20 | 0.003" |

was such that it was not likely to cause a problem during forging. As an added precaution, the hole was filled with a metal rod insert to minimize its effect on metal flow.

After EDM machining, all dies and punches were given a light grit blast on the working surfaces to reduce the shallow surface degredation produced by EDM machining and to provide a matte surface for retaining die lubricants.

### 4.1.3 Preparation of Forging Billets

For both the gear and pinion tool proof forging, AISI 1018 steel was used for tooling set-up and 9310 steel was used for forging test parts which were sent to Litton Precision Gear Co. for verification of tooth geometry. The 9310 grade of steel was used to economically simulate the behavior of AMS 6265 steel because these steel grades have essentially the same composition. An air melt version of 9310 was used.

### 4.1.3.1 Gear Billets

Gear billets were machined to the dimensions of TRW Drawing SK121470-3. The nominal billet size is 3.500 ±.005 diameter x 5.50 long with a 1/2" diameter radius on one end. For set-up, the 1018 billets were machined to various lengths in the range 5.375 to 5.625" for use in determining the optimum billet volume. The 9310 steel billets were machined to final size on the O.D. only. After completion of the tooling set-up, when the optimum billet volume was determined, the 9310 billets were cut to final length. The O.D. surfaces were ground to finish size on all billets to minimize surface machining marks which might act as crack initiation points during forging. After machining, all billets were nickel flash plated to a thickness of .0010 to .0015" as protection against scaling and decarburization during heating. Twelve 1018 steel and ten 9310 steel gear billets were prepared for the tool proofing phase.

### 4.1.3.2 Pinion Billets

The pinion billet configuration is a 3.500 .005" diameter x 5.925 long cylinder with a tapered 6.125" long stem as described in TRW Drawing SK092270. For these billets, the same general scheme of preparation described in Paragraph 4.1.3.1 for gear billets was implemented.

### 4.1.4 Forging

Forging of gears and pinions was performed in accordance with the parameters established during the previous development program. Tooling set-up was accomplished with 1018 steel billets to obtain the configuration shown in the appropriate forging drawings. Because tooth form dimensions are determined by the size of the die cavity and die and billet temperatures, the major set-up parameters were flash and web thickness to assure that the relative location of the teeth with the inner web of the forging was optimum for machining. During tooling set-up, five gear billets and six pinion billets were required to obtain the desired configuration with 1018 steel. After set-up, eight gear and five pinion tool proof forgings were made with 9310 steel. Forging parameters are summarized in Table 4.2.

Some difficulty was experienced in obtaining an even distribution of material around the circumference of gear and the pinion forgings. This problem was found to be associated with the clearance between the press ram and its guides which resulted in random axial misalignment of the punches and dies. Misalignment present during the preform forging resulted in non-symmetrical preform configurations which the affected material distribution at the hot coin station. These alignment problems were not serious enough to prevent filling of the die cavities, but did result in uneven flash distribution in the finish forgings. The same type of uneven flash distribution occurred during the development program and did not affect the finished gear configuration.

The degree of filling obtained for both gear and pinion forgings was comparable to that obtained during the development program. Areas of minor underfill occurred near the top and bottom corners of the teeth, but these areas are not within the finish envelope.

4.1.5 Inspection of Tool Proof Forgings at TRW

Inspection of tool proof forgings consisted of dimensional inspection of flash, web thickness and tooth diameter. A summary of dimensional inspection data for gear and pinion forgings is given in Table 4.3. The forging drawing requirements are also shown for reference. Readings of flash and web thickness were taken at four locations, 90° apart.

For gears, flash thickness was slightly smaller than optimum while other dimensions were within the optimum range. Pinion measurements indicated that flash and web thickness were near nominal but tooth diameter was slightly larger than originally designed. Comparing the dimensions in Table 4.3 with the finished gear dimension, it appears that the machining envelope would be sufficient for machining of all forgings.

4.1.6 Verification of Forged Tooth Geometry at Litton

Three pinion forgings and three gear forgings were sent to Litton Precision Gear Co. for verification of forged tooth characteristics. At Litton the forgings were inspected, process machined and processed through tooth grinding to determine the machining stock envelope on the teeth. A summary of the stock removal results is listed in Table 4.4.

Table 4.2

Forging Parameters for Tool Proof Phase

| | | Gear | Pinion |
|---|---|---|---|
| 1. | Material | 9310 Steel | 9310 Steel |
| 2. | Billet Size | 3.500 diameter x 5.500 long, 1/2" radius on one end. | 3.500 diameter x 11.950 long, 1/2" radius on one end. |
| 3. | Billet Temperature | 2055-2070°F | 2060-2080°F |
| 4. | Tool Temperature (Preform) | 410-470°F | 390-420°F |
| 5. | Tool Temperature (Finish) | 390-420°F | 400-440°F |
| 6. | Furnace Atmosphere | Exogas, 700 $ft^3$/hour | Exogas, 700 $ft^3$/hour |
| 7. | Billet Heating Time | 45 minutes | 45 minutes |
| 8. | Die Lube | F14-C3, graphite | F14-C3, graphite |
| 9. | Transfer Time, Furnace-Press | 6-8 seconds | 8-10 seconds |
| 10. | Transfer Time, Preform-Coin | 6-8 seconds | 10-13 seconds |

Table 4.3

Dimensional Inspection Data for
Tool Proof Forgings

GEARS

| Serial No. | Flash Thickness Aim 0.180 ± 020" 1 | 2 | 3 | 4 | Web Thickness Aim 0.688 ± 020" 1 | 2 | 3 | 4 | Tooth Diameter Aim 8.976 ± 0.15" |
|---|---|---|---|---|---|---|---|---|---|
| TP6 | .155 | .148 | .140 | .148 | .667 | .665 | .661 | .662 | 8.980 |
| TP7 | .160 | .152 | .145 | .150 | .672 | .671 | .668 | .667 | 8.972 |
| TP8 | .161 | .155 | .150 | .155 | .674 | .672 | .670 | .669 | 8.981 |
| TP9 | .158 | .154 | .146 | .148 | .672 | .671 | .667 | .669 | 8.959 |
| TP10 | .162 | .156 | .153 | .152 | .674 | .675 | .665 | .670 | 8.975 |
| TP11 | .158 | .152 | .144 | .148 | .670 | .668 | .667 | .664 | 8.981 |
| TP12 | .159 | .154 | .148 | .151 | .670 | .670 | .665 | .664 | 8.977 |
| TP14 | .158 | .154 | .146 | .148 | .674 | .674 | .666 | .663 | 8.961 |

PINIONS

| Serial No. | Flash Thickness 0.100 ± 020" 1 | 2 | 3 | 4 | Web Thickness 1.863 ± 020" 1 | 2 | 3 | 4 | Tooth Diameter 7.563 ± 010" |
|---|---|---|---|---|---|---|---|---|---|
| TP7 | .100 | .088 | .095 | .109 | 1.876 | 1.874 | 1.873 | 1.880 | 7.565 |
| TP8 | - | .094 | .101 | .109 | 1.869 | 1.872 | 1.875 | 1.876 | 7.575 |
| TP9 | - | .092 | .92 | .105 | 1.878 | 1.878 | 1.873 | 1.878 | 7.580 |
| TP10 | .095 | .104 | .95 | .106 | 1.880 | 1.875 | 1.876 | 1.871 | 7.582 |
| TP11 | .075 | .101 | .107 | .102 | 1.863 | 1.873 | 1.876 | 1.870 | 7.589 |

Table 4.4

Results of Tool Proof Gear and Pinion Machining and Inspection

| Description | S/N | Range of Stock Removal (inch) Coast Side | Drive Side | Root | Magnaflux Surface Inspection |
|---|---|---|---|---|---|
| A. Gear | | | | | |
| Optimum | | .007-.010 | .007-.010 | .007-.010 | |
| Results Obtained During Development | | .008-.011 | .008-.011 | .007-.014 | |
| Tool Proof Results | TP.6 | All .007-.010 | | .002-.007 | O.K. - No Indications |
| | TP.9 | | | | O.K. - No Indications |
| | TP.11 | | | | O.K. - No Indications |
| B. Pinion | | | | | |
| Optimum | | .007-.010 | .007-.010 | .007-.010 | |
| Results Obtained During Development | | .008-.013 | .005-.008 | .005-.014 | |
| Tool Proof Results | TP.7 | .009 | .003 | .003 | All parts exhibited line indications on 1-2 teeth. |
| | TP.9 | .012 | .004 | .004 | |
| | TP.11 | .010 | .005 | .006 | |

Results for the gear indicated that the gear forging tooling configuration was near optimum and required no rework for this program. Pinion stock removal results were further from the optimum range but complete clean up of tooth surfaces was accomplished without excessive stock removal. The vendor indicated that the low range of stock removal on the pinion tooth drive sides could be increased to the optimum range if the coast sides were cut shallower. During these machining trials, the coast side was inadvertantly cut too deep (.009-.012) which then limited the range of stock removal available on the drive side. The total ranges of stock removal for the coast and drive sides were near optimum. With these results it was concluded that the tooth form configuration in the pinion die is not significantly different from that obtained during development and should be used for production forging.

Magnaflux tests performed on the pinion tooth surfaces indicated line defects on 1-2 teeth on all three test pieces. These crack indications would cause rejection if present on production parts. Because the cracks consistently occurred near the area of minimum flash, it was assumed that the cracking problem was associated with die alignment. Therefore, these defects were not considered to be cause for tooling modification and the tooling and equipment was considered to be ready for production forging.

## 4.2 Production Forging

Results of gear tooth machining performed on tool proof forgings, described in Section 4.1, indicated that the configuration of the tooth form forging dies was within the optimum range. Therefore production forging activity was immediately initiated.

### 4.2.1 Procurement and Inspection of Billet Material

Forging billet material was procured to the requirements of AMS 6265 as set forth in the contract and applicable Boeing drawings. Material was purchased in the form of 6-8 foot lengths with a rough machined O.D. of 3.520-3.536. Certifications showing chemical analyses and metallurgical and mechanical properties as supplied by the material vendor are reproduced in Figure 4.1. Original copies of the certifications are on file at TRW. TRW inspection of billet material consisted of a review of the vendor's material certification and dimensional inspection of length and O.D.

### 4.2.2 Billet Preparation (Gears and Pinions)

In preparation for production forging, forty-two (42) AMS 6265 gear and pinion billets were machined to Drawings SK121470-3 and SK092270 respectively. The O.D. surfaces of the billets were finish ground to a surface finish of 32 rms or better to minimize the presence of machining marks which could act as crack initiation points during forging. A ground finish is also desireable to minimize die friction during forging and to promote a smooth surface in the finished part which would facilitate set-up for tooth form grinding.

# ALLEN-FRY STEEL COMPANY

5524 ALCOA AVENUE - VERNON, CALIFORNIA 90058
TELEPHONE 582-0611

No. 103726
103726

## CERTIFIED TEST REPORT

VAN DYKE DETROIT
3204 N MAIN STREET
ROYAL OAK, MICHIGAN 48073

SHIP TO . T R W INC
23555 EUCLID AVENUE
CLEVELAND, OHIO 44117

REF# 88-333-157

SHIP TO SAME AS SOLD TO UNLESS OTHERWISE NOTED

| CUSTOMER'S ORDER NUMBER | ORDER DATE | ENTERED BY | PARTIAL SHIPMENT ☐ / COMPLETE ORDER ☐ | ATTN. | NUMBER REQUIRED |
|---|---|---|---|---|---|
| PO# 11881 | 8-8-73 | GLYNN G | | VG 2 | |

| MILL SOURCE | COLOR | SIZE & DESCRIPTION |
|---|---|---|
| Republic | Brown & Yellow | 3.520/3.536" Rd. RT E-9310 Norm & Temp Vac Melt AMS 6260H AMS 6265C AMS 2300 Chems to MIL S 7393C Comp 3 |

CHEMICAL ANALYSIS

| HEAT NO | C | MN | P | SU | SI | CR | NI | MO | VA | AL | SE | TI | CU | CB | COB | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 3963047 | .100 | .65 | .004 | .004 | .26 | 1.35 | 3.30 | .15 | | | | | .16 | | | |

PHYSICAL PROPERTIES

| | YIELD LBS/SQ. IN. | TENSILE STRENGTH LBS/SQ. IN. | ELONG % IN IN | RED OF AREA % | BRINELL | ROCKWELL | EHN GRAIN SIZE | DECARB | MACRO | MICRO | EMBR | HARDENABILITY | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SEE PAGE TWO FOR ADD. | INFO.-AIRMELT HEAT # | | | | 217 8011446 | | | OK | OK | | | | | |

Electrode # 6

SUBSCRIBED AND SWORN TO BEFORE ME

THIS 22nd DAY OF Oct. 19 73 DO

NOTARY PUBLIC
IN AND FOR THE COUNTY OF LOS ANGELES, STATE OF CALIFORNIA

THE ALLEN-FRY STEEL CO. CERTIFIES THAT THIS IS A TRUE COPY OF THE ORIGINAL MILL TEST REPORT NOW ON FILE AND THAT THE SPECIALTY METAL COVERED BY THIS TEST REPORT WAS MELTED IN A STEEL MANUFACTURING FACILITY LOCATED IN THE UNITED STATES OR ITS POSSESSIONS

BY Donald K. Mackey
AUTHORIZED CERTIFICATION CLERK

Figure 4.1 Test Report for AMS 6265 Forging Billet Material.

PAGE 2

Type 9310 N & T VM
VM Heat # 3963047
Size: 3.520/3.536" Rd.

VACUUM ARC REMELT PRODUCT OF AIR MELT 8011446

| VAR NO. | CHEMISTRY | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | CARBON | MANG | PHOS | SUL | SIL | COPPER | NICKEL | CHROME | MOLY | VAN | CO | | | | |
| | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | |

| QUALIFICATION TEST VAR NO. | | MAGNAFLUX | | | | | J K RATING | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | FREQ. | SEV. | TOTAL IND. | ACC LENGTH | VAR NUMBER | A THIN | A HEAVY | B THIN | B HEAVY | C THIN | C HEAVY | D THIN | D HEAVY |
| #1 | TOP | 00 | 00 | 0 | 0 | 3963047 | 1.0 | 0 | 0 | 0 | 0 | 0 | 1.0 | 0 |
| 3832227 | BOT | 00 | 00 | 0 | 0 | #6 | 1.0 | 0 | 0 | 0 | 0 | 0 | 1.0 | 0 |
| | TOP | | | | | | | | | | | | | |
| | BOT | | | | | | | | | | | | | |
| #7 | TOP | 00 | 00 | 0 | 0 | | | | | | | | | |
| 3963049 | BOT | 00 | 00 | 0 | 0 | | | | | | | | | |

| TEST VAR NO. | | JOMINY (EXPRESSED IN 16THS) | | | | | | | | | | | | | | | | | DEV. HARDNESS | GRAIN SIZE |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 10 | 12 | 14 | 16 | 18 | 20 | 24 | 28 | 32 | | |
| #1 | TOP | 37 | | | | | 37 | | | | | | | | | | | | | 7/8 |
| | BOT | 38 | | | | | 38 | | | | | | | | | | | | | 7/8 |
| | TOP | | | | | | | | | | | | | | | | | | | |
| | BOT | | | | | | | | | | | | | | | | | | | |
| #7 | TOP | 39 | | | | | 38 | | | | | | | | | | | | | 7/8 |
| | BOT | 40 | | | | | 40 | | | | | | | | | | | | | 7/8 |

| | VAR NO. | AS SHIPPED BHN |
|---|---|---|
| ULTRASONIC | | / |
| ULTRASONIC | | / |
| ULTRASONIC | | / |
| ULTRASONIC | | / |
| MACRO ETCH SATISFACTORY | | / |
| MICRO | | / |

Figure 4.1 (Continued). Page 2 of Test Report for AMS 6265 Forging Billet Material.

After machining, all billets were nickel flash plated to a plating thickness of .0010 to .0015 as protection against scaling and decarburization during heating.

### 4.2.3 Production Forging (Gears)

Production forging of gears was carried out using the same heating and forging parameters used during the tool proofing phase. The forging press was modified to increase flywheel speed and the die nest and tooling was installed and set-up. Billets machined from mild steel were used to achieve tool alignment and flash thickness comparable to that obtained during the tool proofing run.

Actual forging of AMS 6265 billets was carried out in batches of five pieces which was convenient for billet heating. Five billets were charged at 5 minute intervals in a rotary hearth resistance heated furnace with an exogas atmosphere. After 45 minutes of heating at 2050°F, billets were removed for forging at 5 minute intervals which resulted in a uniform total heating time for all billets. After each forging run of 5 billets, one of the forgings was measured for flash thickness and web thickness before proceeding to the next forging run in order to insure that proper die alignment was being maintained. Forgings were air cooled and then serialized with a metal stamp after forging. A total of 39 forgings were produced with AMS 6265 steel.

### 4.2.4 Cleaning and Removal of Nickel Coating (Gears)

In preparation for inspection and eventual heat treating, carburizing and gear finishing, forgings were subjected to a sequence of grit blasting and chemical treatment to remove scale and to dissolve the nickel coating. Removal of the nickel coating is essential in order to provide a suitable surface for carburizing.

### 4.2.5 Inspection of Forgings (gears)

Dimensional inspection of the gear forgings consisted of measurement of flash thickness and web thickness (both at 4 locations) and of the overall tooth diameter. Results of dimensional inspection, listed in Table 4.5 indicate that these production forgings are essentially identical to those forged for the tool proofing phase. Thus, the production forging run for gears was successfully completed.

### 4.2.6 Production Forging (Pinion)

Results of pinion machining on tool proof forgings performed at Litton indicated that although the tooth form configuration was acceptable, the forgings each contained a crack defect on 1-2 teeth which would be cause for rejection during finishing. Because the crack consistently occurred near the

Table 4.5

Dimensional Data - Gear Forgings

| Forging Serial No. | Flash Thickness Range (in.) | Web Thickness Range (in.) | Tooth Form Diameter (in.) |
|---|---|---|---|
| 1 | .149-.171 | .672-.678 | 8.993 |
| 2 | .155-.174 | .677-.679 | 8.996 |
| 3 | .146-.175 | .672-.681 | 9.002 |
| 4 | .149-.171 | .677-.683 | 8.982 |
| 5 | .148-.175 | .672-.677 | 8.990 |
| 6 | .147-.168 | .676-.678 | 8.990 |
| 7 | .148-.169 | .673-.677 | 8.985 |
| 8 | .154-.173 | .675-.681 | 8.986 |
| 9 | .148-.167 | .673-.679 | 8.986 |
| 10 | .153-.176 | .675-.681 | 8.986 |
| 11 | .149-.166 | .671-.675 | 8.988 |
| 12 | .147-.175 | .673-.677 | 8.989 |
| 13 | .151-.169 | .673-.676 | 8.988 |
| 14 | .147-.171 | .673-.676 | 8.981 |
| 15 | .148-.170 | .673-.676 | 8.980 |
| 16 | .150-.166 | .671-.674 | 8.997 |
| 17 | .148-.168 | .673-.675 | 8.981 |
| 18 | .148-.170 | .675-.677 | 8.988 |
| 19 | .150-.172 | .672-.677 | 8.993 |
| 20 | .148-.164 | .672-.678 | 8.985 |
| 21 | .151-.174 | .675-.681 | 8.992 |
| 22 | .150-.167 | .670-.680 | 8.993 |
| 23 | .153-.170 | .677-.682 | 8.988 |
| 24 | .153-.175 | .675-.681 | 8.982 |
| 25 | .156-.180 | .675-.682 | 8.992 |
| 26 | .149-.169 | .675-.679 | 8.986 |
| 27 | .154-.170 | .675-.679 | 8.989 |
| 28 | .148-.171 | .673-.678 | 8.986 |
| 29 | .153-.172 | .678-.679 | 8.977 |
| 30 | .151-.173 | .676-.681 | 8.989 |
| 31 | .150-.174 | .675-.678 | 8.993 |
| 32 | .150-.173 | .678-.684 | 8.982 |
| 33 | .149-.172 | .678-.682 | 8.985 |
| 34 | .154-.177 | .680-.683 | 8.996 |
| 35 | .141-.169 | .677-.681 | 8.983 |
| 36 | .149-.169 | .674-.680 | 8.990 |
| 37 | .152-.168 | .673-.679 | 8.985 |
| 38 | .146-.174 | .673-.679 | 8.997 |
| 39 | .151-.170 | .674-.680 | 8.990 |

area of minimum flash, it was assumed that the cracking problem was associated with die alignment. Therefore, production forging was undertaken with the intention of improving die alignment to remedy the cracking problem.

Tooling was installed and set-up using mild steel billets. Various components of both the preform and hot coin tooling were rotated to minimize the stack up of misalignment which can occur in the overall set-up. Alignment was then measured by lead readings taken at 4 locations 90° apart near the circumference of the working tools. These readings indicated a total range of less than .006" for the preform side and less than .003" for the finish side. A slight modification was also made to the stem of the pinion billet to insure positive seating during forging as a precaution against misalignment due to slop in preform location. These alignment procedures resulted in improved flash distribution around the circumference of the pinion.

Production forging with AMS 6265 billets was performed with the same furnace heating procedures used with the gears except that only three billets were charged per furnace load. The crack defect appeared in some of the forgings early during the forging run and therefore the forging run was temporarily discontinued to again analyze the problem. Because alignment was good, other possible causes were considered.

It was first assumed that the crack defect occurs during the hot coin blow and is not present in the preform. This was determined by visual inspection of a number of preforms. The possibility of thermal cracking was also investigated because of the large variation in section size in the pinion forging. The following steps were taken to minimize temperature differences while the forging was in contact with the die and during cooling after forging.

1. The forging temperature was lowered from 2050 to 1950°F.
2. The billets were treated with a ceramic coating.
3. Forgings were slow cooled in sand graphite mixture.
4. Dies were reheated after each blow.

These variations resulted in a slight decrease in the apparent length of the crack but did not decrease the frequency of occurrence of cracks.

During forging there was no practical way to positively determine whether or not a given forging was cracked unless the crack could be seen visually. Because of the tightness of the crack it was difficult to determine whether or not the apparently uncracked forgings were in fact good. Because of this uncertainty combined with the problem of limited equipment time availability, the forging run was continued in an attempt to obtain as many good forgings as possible using the available billets. A total of forty-one (41) forgings were produced.

4.2.7 Cleaning and Removal of Nickel Coating (Pinions)

All forgings were blasted and chemically treated to remove scale and to dissolve the residual nickel coating.

4.2.3 Inspection (Pinions)

Immediately after cleaning and nickel removal, the pinion forgings were dye penetrant inspected to assess the extent of the cracking problem. Dye penetrant results for the forty-one (41) forgings were as follows:

17 pieces - no indications

3 pieces - minor indications

21 pieces - major crack indications on 1-2 teeth

41 pieces total

Dye penetrant inspection revealed cracks on a number of forgings which passed cursory visual examination. No apparent relationship between forgings parameters and crack occurrence was found.

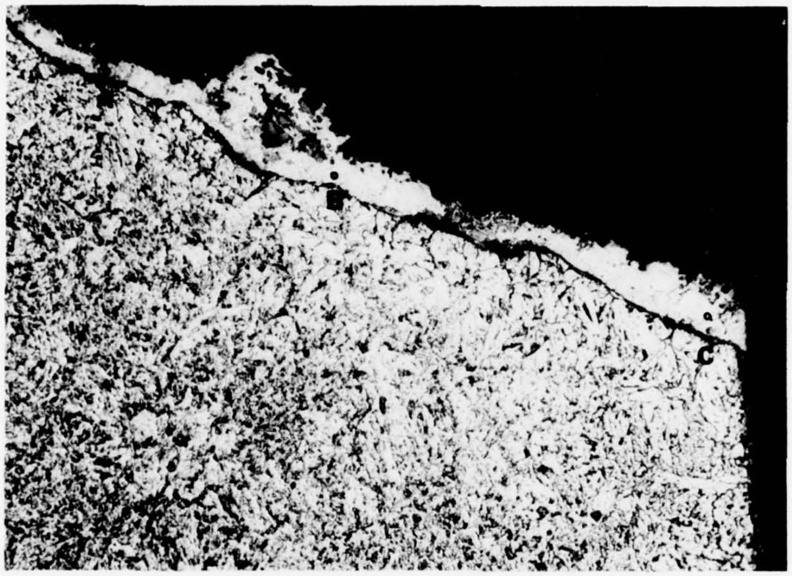
4.2.9 Analysis of Pinion Defects

The analysis of pinion defects encountered during forging was continued. To establish the nature of the defect, an electron microprobe analysis was performed on the cross section of the defect surface film at the locations shown in Figure 4.2. Quantitative analysis of characteristic radiation emitted by the surface film identified the film as residual nickel plating. Measured nickel contents for three locations obtained by measuring $K_\alpha$ radiation intensity of the specimen versus a known standard, are shown in Figure 4.2. This data identified the forging defects as laps or seams and it was assumed that these occurred during the final forging blow.

Remedial action for this type of defect would normally consist of preform and tooling design modifications to adjust metal flow characteristics during the hot coin blow. This action may require several time consuming design iterations which were not intended in the original scope of the program. Therefore, in the interest of providing the required test parts, TRW proceeded with plans for a second pinion forging run anticipating the same level of scrap rate experienced during the initial production run.

4.2.10 Billet Preparation For The Second Pinion Forging Run

Billet material for the second pinion forging run was procured. The material was received in two heat lots, both conforming to AMS 6265. (One of the heats was the same as that procured for the previous forging run.) Material certification for the other heat is reproduced in Figure 4.3 and is retained on file at TRW.



| Location | Weight % Ni |
|---|---|
| A | 78.4 |
| B | 72.2 |
| C | 66.6 |

Figure 4.2. Nickel Content of Surface Film on Pinion Tooth Defect. 250X

VAN DYKE-DETROIT
3204 NO. MAIN STREET
ROYAL OAK, MICHIGAN 48073

**TEST REPORT**

SOLD TO
TRW CORPORATION
Box 3220
Cleveland, OH 44117

RECEIVED
OCT 14 1974
Mtrls. Tech. Purch.

359083

| OUR ORDER NO | YOUR ORDER NO | SALESMAN | TERMS | SHIPPED VIA | PPD OR COLL |
|---|---|---|---|---|---|
| 14661-1 | 88-35903 | Detroit | ½-1% 10, Net 30 Days | Transcon | X |

| MILL SOURCE | COLOR | |
|---|---|---|
| Timken | Brown & Yellow | 3.520" Rd. RT E-9310 Vac Melt Norm & Temp AMS 6260H AMS 6265C AMS 2300 HT-5042 HT-42F Chems to MIL S 7393C Comp III |

CHEMICAL ANALYSIS

| HEAT NO | C | MN | P | SU | SI | CR | NI | MO | VA | AL | SE | TI | CU | CB | COB | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2V6486 | .09 | .61 | .009 | .007 | .26 | 1.29 | 3.25 | .13 | | | | | .15 | | | |

PHYSICAL PROPERTIES

| | YIELD LBS/SQ IN | TENSILE STRENGTH LBS/SQ IN | ELONG % IN IN | RED OF AREA % | BRINELL | ROCK WELL | EHN GRAIN SIZE | DECARB | MACRO | MICRO | EMBR | HARDENABILITY | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SEE PAGE TWO FOR ADD. INFO.-AIRMELT HEAT # 61980 | | | | | 179 (As Shipped) | | | OK | OK | | | | | |

Ingot # 4

SUBSCRIBED AND SWORN TO BEFORE ME THIS 30th DAY OF September 19 74

Helen R. Miller
NOTARY PUBLIC, OAKLAND COUNTY, MICHIGAN
MY COMMISSION EXPIRES 3-5-78

I hereby certify that the above information is taken from chemical and metallurgical reports on file at our office.

By Sandra Kollarz

Figure 4.3. Material Certification.

The billet material was machined into forging billets, incorporating a slight modification to the billet design to provide added billet volume. This modification consisted of adding 0.100 inch to the billet length which increased the total length from 11.950 to 12.050 inches. The increased length was intended to provide a more uniform distribution of forging flash with the intent of helping to alleviate the forging crack problem. After machining, the billets were inspected and nickel plated in accordance with previously described procedures.

#### 4.2.11 The Second Pinion Forging Run

The second pinion forging run was concerned with both production forging of pinions to produce the hardware required for finishing, and forging tests to determine the cause of forging line defects found in pinions. This production and testing activity was run concurrently with the intention of using defect-free forgings produced during testing to meet production requirements.

Forging tests to remedy the forging line defect problem consisted of the following specific approaches:

1. The variation of billet volume to determine the influence of die filling and flash characteristics.

2. Zyglo inspection after the preform blow to detect possible defect initiation in the preform stage.

3. Monitoring of defect occurrence and location as related to die position, orientation and occurrence of flash and die alignment.

After normal forging preparation consisting of forge press modification, die nest and tooling installation and alignment, and heating furnace preparation, trial forging was initiated using the same procedure used during the first forging run. As anticipated, this procedure resulted in a high scrap rate due to same type of line defects found over 1-2 teeth during the previous run. In subsequent forging trials in which the above test variations and procedures were used, it was found that billets with increased volume and a matte surface finish resulted in a high percentage of defect-free forgings. Also, Zyglo surface inspection of parts which had been cooled down after the preform blow detected the line defect (approximately 3/4 - 1 1/2" long) at this preform stage; and after reheating and forging, this line defect was positively traced to the defect which had been occurring on the final part. This line defect had previously eluded detection in the preform stage, probably because of its intermittent occurrence.

Examination of the line defect indicated that it is a tight forging lap which occurs during the preform blow and which is carried over to the finish blow. The lap occurs with a circumferential orientation in the preform and is not visually detectable during transfer of the preform to the finish die when the part is hot. If the preform is cooled down, the defect can be visually detected and can be quickly removed by simple grinding. For future production the defect can be eliminated by the use of larger volume billets in which the surfaces in contact with the die have been ground to produce a matte finish without circumferential tool marks. Specifically, a billet length of 12.050" and a matte surface finish of 16-20 rms will produce defect free forgings.

Having established the nature of and the remedy for the line defect which had been occurring in pinion forgings, forging trials were continued to produce sufficient parts for finishing and to further investigate the defect problem. Using the available billets with larger volume and ground surface, sufficient parts were produced as required to complete the finishing requirements. However, during the final stages of forging, the tooth form die fractured. Although the fracture was completely through the die in three places, the design of the die holding fixture was such that forging was continued, for test purposes only, with the fractured die. These last forging trials with the fractured die were made to verify the cause and remedy of the line defects.

Parts produced during this second pinion forging run were processed through blasting and nickel stripping and were Zyglo inspected for line defects. Twelve forgings which were free of defects and which were made before die cracking occurred were set aside for finishing. This completed the pinion forging requirements.

## 4.3 Gear Finishing

In accordance with the Description of Work in the contract, the forged gear blanks produced at TRW were finish fabricated to Boeing Engineering Drawings SK22270 (114D6245) and SK22269 (114D6244). Finishing was subcontracted to Litton Precision Gear Co., Chicago, Illinois. Litton is the current supplier of this gear set to Boeing and participated in the finishing of the forged gear blanks during process development.

A total of 35 gears and 17 pinions for the first forging run were sent to Litton. This first subcontract was for finishing 26 gears and 14 pinions with the balance of the forgings to be used as spares if required.

In view of the high scrap rate experienced during previous finishing trials, ways to minimize scrap losses were discussed with the vendor. The vendor pointed out that high scrap problems experienced in the past were usually a result of some small localized defect which could not be assessed in the as-forged condition. As a result, the defect exhibited itself only during finish grinding at which point a considerable investment had already been made in the part.

To minimize these potential high scrap losses, a preliminary green grinding operation was added as a screening procedure before heat treating and finish grinding. The inexpensive green grind operation was used to remove a minimal amount of stock from the tooth surface to determine the potential for cleaning up during finish grinding. After passing the green grind test, the part was carburized, heat treated and finish ground as normal. Because of the small amount of material removed (about .002-.005") this scheme did not significantly affect the relationship of forging flow lines to the tooth geometry. Also, since the green grind was performed before heat treatment, the amount of stock removed after carburizing was not affected. Green grinding was successful in determining that the gear and pinion forgings from the first forging run were sound and suitable for final finishing.

To complete the deliverable gear finishing requirements, twelve (12) forgings from the second pinion forging run were sent to Litton as a second batch while the first batch was in process.

Among the 35 gears and 17 pinions from the 1st forging run sent to Litton for finishing, Litton selected the 26 gear forgings and 14 pinion forgings which they judged, by visual examination, to have the best tooth surface finish and therefore the optimum finishing characteristics. These selected forgings all yielded good parts and demonstrated an acceptable pattern of stock removal on the tooth forms. Likewise, all forgings from the second pinion forging run yielded good finished parts.

TRW received written certification that the finished gears and pinions met the requirements of Boeing Drawings SK22270 and SK22269 and that the parts were processed within a quality system conforming to MIL-Q-9859A.

Within the course of finishing operations at Litton, a number of minor deviations to the Boeing prints were generated, and approval of these deviations was obtained from AVSCOM after technical consultation with Boeing. It should be pointed out that these deviations were judged to be typical of those normally experienced on these parts and that the deviations were not associated with the forging process.

A list of delivered gear and pinion part serial numbers showing heat number and approved deviations is given in Tables 4.6 and 4.7 respectively.

Table 4.6

List of Finished Gears Made From Precision Forgings
Boeing Drawing SK22270

| Serial No. | Material Heat No. | Approved Deviations |
|---|---|---|
| M101 | Rep. 3863047 | 2.445 M.D. is .005 over maximum. .0095 maximum stock removal was .013 in root. |
| M102 | " | 3.2500 + .0005-.0000 I.D. Checks 3.2507 |
| M103 | " | .003/.006 backlash checks .007. |
| M104 | " | 2.445 M.D. is .005 over maximum. |
| M105 | " | 2.445 M.D. is .005 over maximum. .0095 maximum stock removal was .012 in root. |
| M106 | " | " " " " " " " " " " " " " " |
| M108 | " | 3.2500 + .0005-.0000 I.D. checks 3.2507. |
| M109 | " | 2.445 M.D. is .005 over maximum. |
| M110 | " | " " " " " " |
| M112 | " | " " " " " " |
| M115 | " | " " " " " " |
| M117 | " | " " " " " " |
| M118 | " | " " " " " " |
| M119 | " | " " " " " " |
| M120 | " | .0095 maximum stock removal was .016 in root. |
| M121 | " | .003/.006 backlash checks .008. .0095 maximum stock removal was .013 in root. |
| M122 | " | 2.445 M.D. is .005 over maximum. |
| M124 | " | " " " " " " |
| M125 | " | " " " " " " |
| M126 | " | " " " " " " |
| M127 | " | " " " " " " |
| M128 | " | " " " " " " |
| M135 | " | " " " " " " |
| M123 | " | " " " " " " |
| M129 | " | 3.2500 + .0005-.0000 I.D. checks 3.2509. |
| M133 | " | " " " " " " " |

Table 4.7

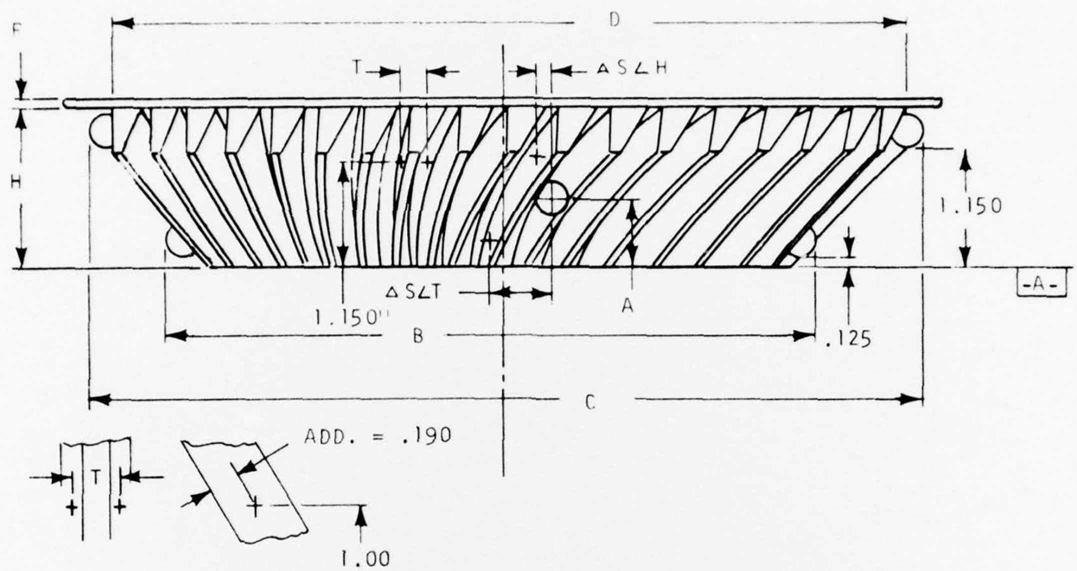
List of Finished Pinions Made From Precision Forgings
Boeing Drawing SK22269

| Serial No. | Material Heat No. | Approved Deviations |
|---|---|---|
| M102 | Rep. 3963047 | .003/.006 backlash is .003 over maximum. .0095 maximum stock removal is .013 on side. |
| M103 | " | |
| M104 | " | |
| M107 | " | .0095 maximum stock removal is .012 on side of tooth. |
| M110 | " | .0095 maximum stock removal is .012 on side of tooth and root. |
| M111 | " | |
| M112 | " | |
| M117 | " | |
| M101 | " | |
| M108 | " | |
| M109 | " | |
| M113 | " | |
| M123 | " | |
| M124 | " | |
| M125 | " | |
| M126 | " | |
| M127 | 2V-6468 | |
| M128 | " | |
| M129 | " | |
| M130 | " | |
| M131 | " | |
| M132 | " | |
| M133 | " | |
| M106 | Rep. 3963047 | Reworked for core in case area on 2.7567 bearing. |
| M115 | " | " " " " " " " " " |
| M116 | " | " " " " " " " " " |

## 5.0 SPECIAL DIMENSIONAL DATA

This section presents specific tabulated dimensional data required by Section F.2 of the contract. The data consists of inspection measurements performed on forged gears and pinions at a 10% inspection level and on plastic die moldings made from the tooth form die. The specific characteristics inspected are shown schematically in Figure 5.1 and the required tabulated data for gear forgings, pinion forgings and die moldings are presented in Table 5.1.

The procedure used for performing the inspections is set forth in Appendix A of the final report to Contract DAAJ01-69-C-0614.




DIMENSIONS ~ .000

| ITEM | A | .2500'' BALL DIA. B | .2812'' BALL DIA. C | D | F | H | ΔS∠T | ΔS∠T | T |
|---|---|---|---|---|---|---|---|---|---|
| MOLDING | ✓ | ✓ | X | X | X | X | X | X | ✓ |
| ELECTRODE | X | X | X | X | X | X | X | X | X |
| FORGING | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | X | X | ✓ |
| CUT MASTER GR | X | X | X | X | X | X | X | X | X |

Figure 5.1 Schematic of Required Dimensional Inspection on Forgings and Die Moldings.

Table 5.1

Inspection Data

| | A | B | C | D | F | H | T |
|---|---|---|---|---|---|---|---|
| Gear Forging M105 | 1.127 | 6.437 | 9.204 | 8.990 | .162 | 1.595 | .258 |
| Gear Forging M115 | 1.131 | 6.430 | 9.221 | 8.980 | .159 | 1.601 | .259 |
| Gear Forging M125 | 1.139 | 6.439 | 9.200 | 8.992 | .168 | 1.598 | .255 |
| Pinion Forging M103 | 1.363 | 5.417 | 7.780 | 7.575 | .112 | 1.756 | .298 |
| Pinion Forging M109 | 1.377 | 5.419 | 7.773 | 7.571 | .106 | 1.650 | .303 |
| Pinion Forging M115 | 1.349 | 5.425 | 7.794 | 7.578 | .101 | 1.761 | .302 |
| Gear Die Molding | 1.143 | 6.444 | - | - | - | - | .285 |
| Pinion Die Molding | 1.380 | 5.431 | - | - | - | - | .318 |

## 6.0 CONCLUSIONS

1. Gear and pinion forgings produced during this program exhibited good tooth form characteristics with an acceptable grinding stock envelope. This indicates that the tooling methods developed earlier are suitable for production use.

2. The most serious manufacturing problem with this process is the difficulty in positively detecting small surface defects or tooth form irregularities which may not clean up during finishing. Because a forged surface inherently contains some surface irregularities, it is difficult to judge the depth of these surface features and their affect on the ability of the part to be finished within the required grinding envelope.

3. The addition of a preliminary green grind as a screening procedure performed before finishing appears to be a worthwhile procedure in view of the relatively low cost involved. This procedure screens parts which may contain hidden surface defects or tooth form irregularities and also provides a smooth surface for locating during finishing.

4. The importance of maintaining accurate forging tool alignment was demonstrated during this program. Slight misalignment, as would be caused by slop in the forging press ram, can cause tool failure. The tooth form die is the most susceptible to breakage because the tooth configuration is a natural notch form. Also, the pinion tooling is more susceptable to breakage than the gear tooling.

5. Successful performance of the TRW forged gears in the qualification tests being conducted by Boeing would provide a viable alternative to total Gleason machining of such high performance components.

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